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Low Density Materials

09 MAR 2012

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Program Manager
AFOSR/RSA
Air Force Research Laboratory

Report Documentation Page

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2012 AFOSR SPRING REVIEW

NAME: Low Density Materials

PORTFOLIO DESCRIPTION :

Transformative research targeting advanced materials that enable substantial reductions in system weight with enhancements in performance and function.

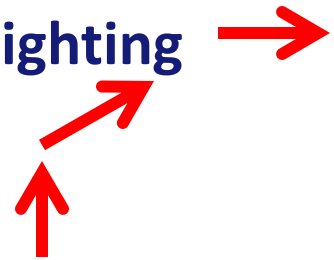
Research within the portfolio is focused on INCREASING the SPECIFIC PERFORMANCE of aerospace platforms.

PORTFOLIO SUB-AREAS:

Structural Lightweighting

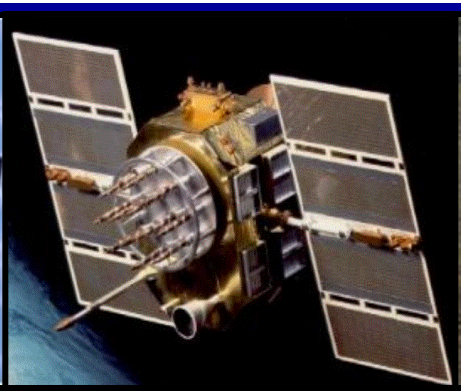
Multifunctionality

Hybrid Materials



Increased emphasis on forging interdisciplinary teams to address broad-base challenges

Why Low Density Materials?

If it has structure and rises above the ground, material density is important!

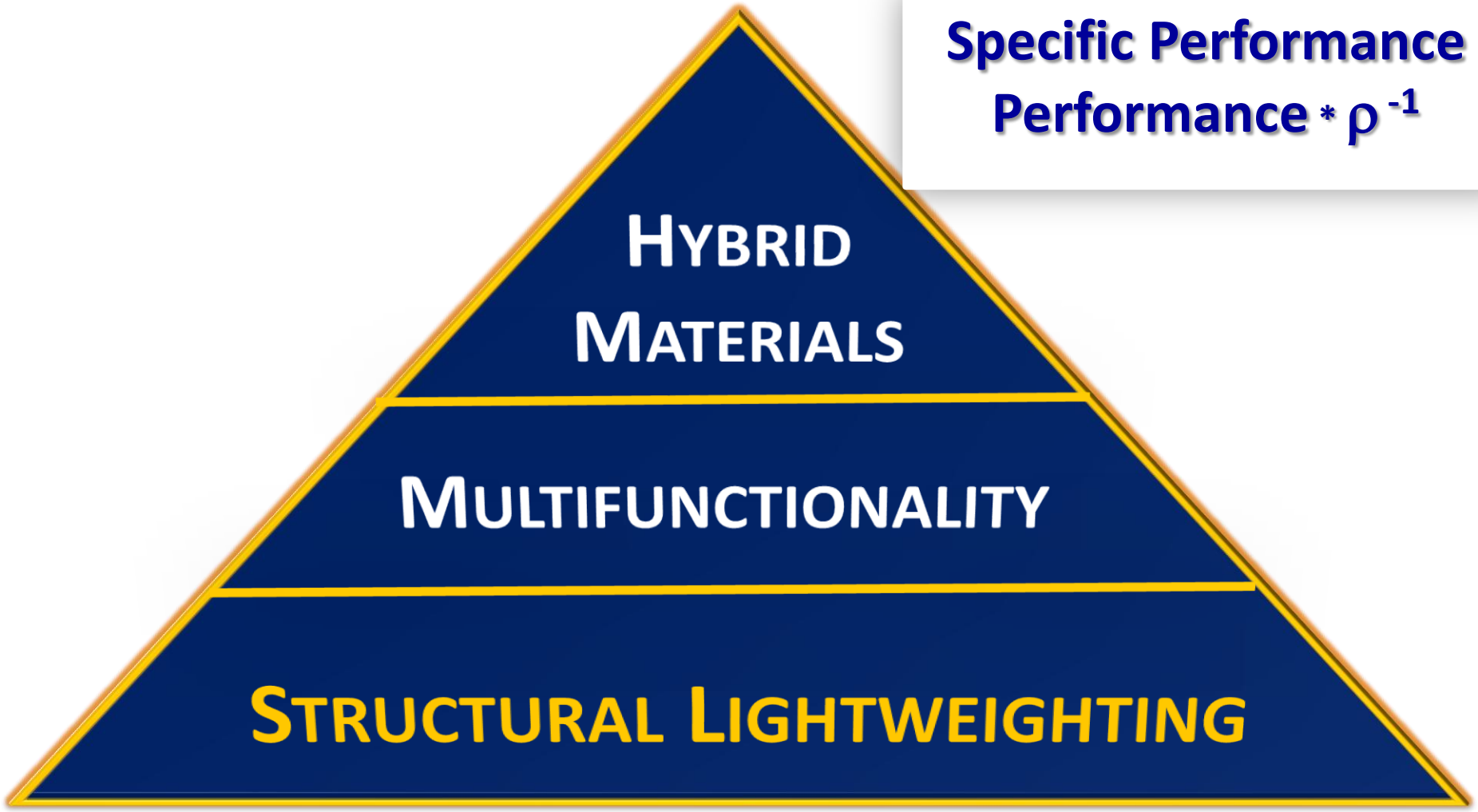



Material density impacts: payload capacity, range, cost, agility, survivability, environmental impact….

Increasing Specific Performance in Aerospace Platforms

Specific Performance

Performance $* \rho^{-1}$



Polyimide Nanofiber Reinforced Structures

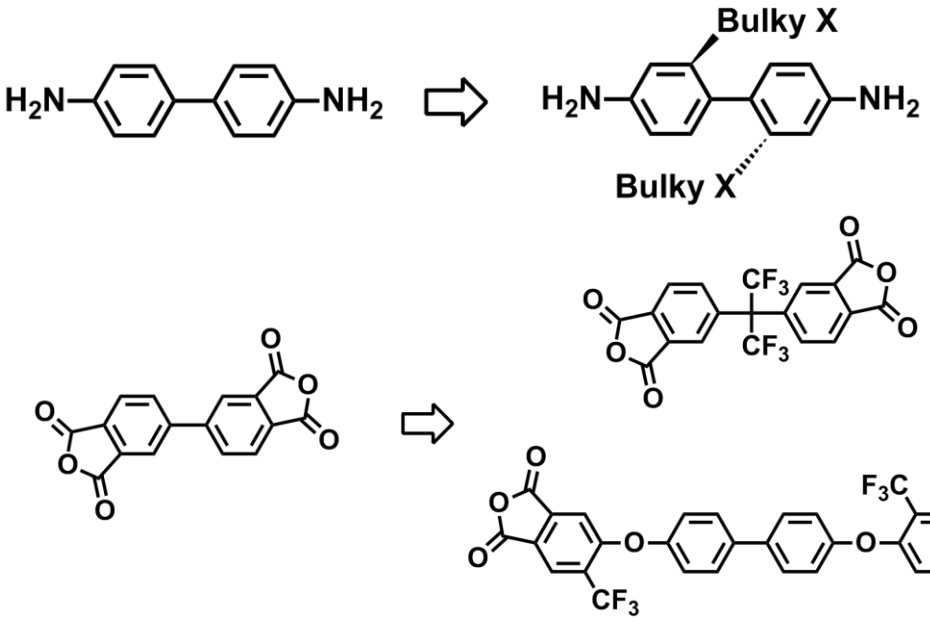
Novel Material Synthesis

Incorporating steric hindances and reduced chain periodicity to achieve:

- Organo-solubility

- Structural rigidity and toughness

- High thermal stability



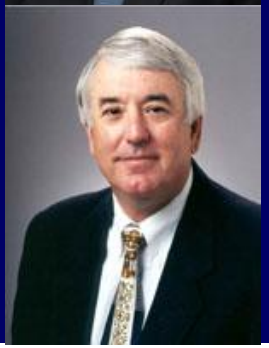
Dr. Yuris Dzenis
McBroom Professor

University of Nebraska Lincoln

Dr. Stephen Cheng
NAE
Robert C. Musson
Trustees Professor

The University of Akron

Dr. Frank W. Harris
Distinguished
Professor
Emeritus



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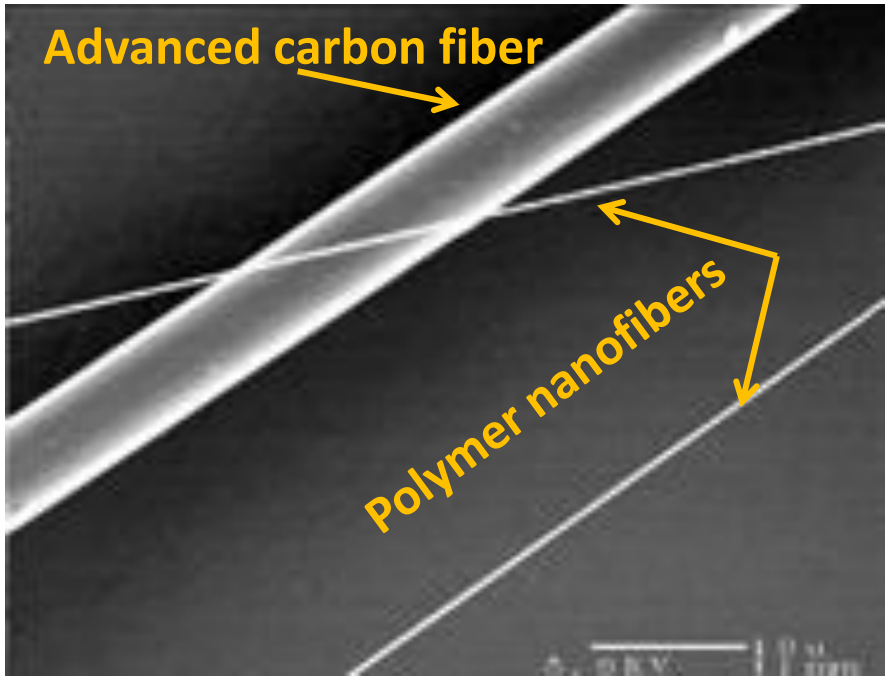
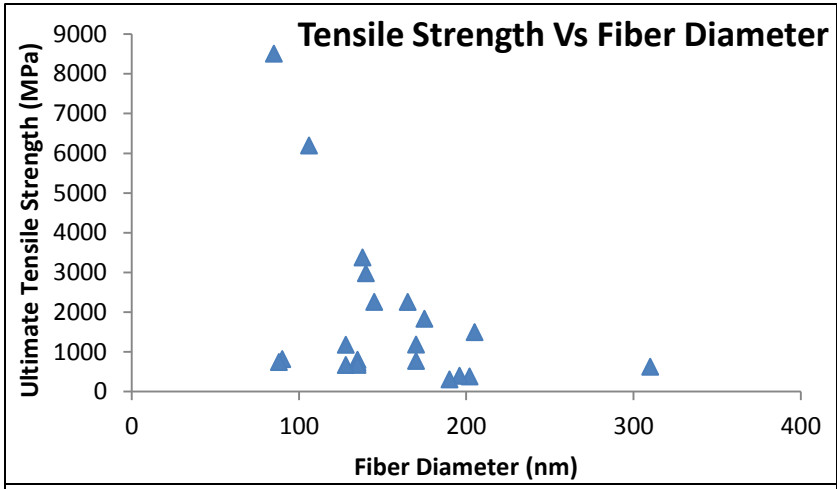
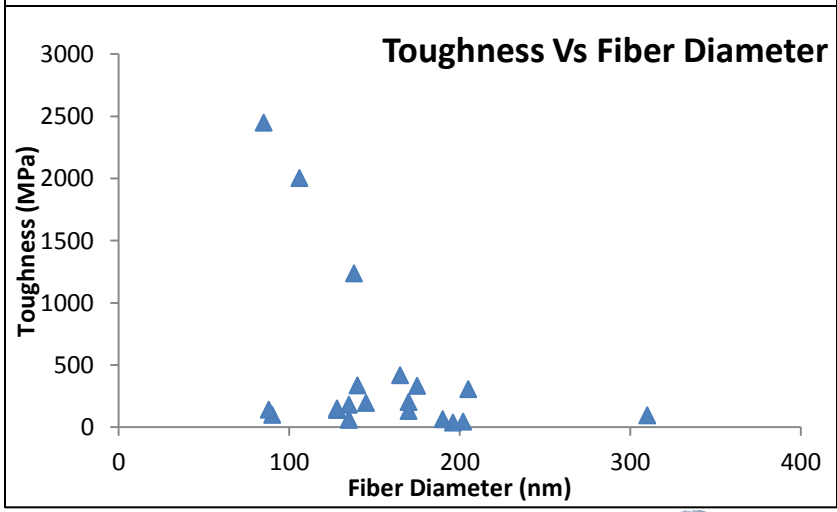
Nanofiber Reinforced Structures

High Strength, Tough Polyimide Nanofibers







Continuous nanofibers electrospun from novel, soluble polyimide

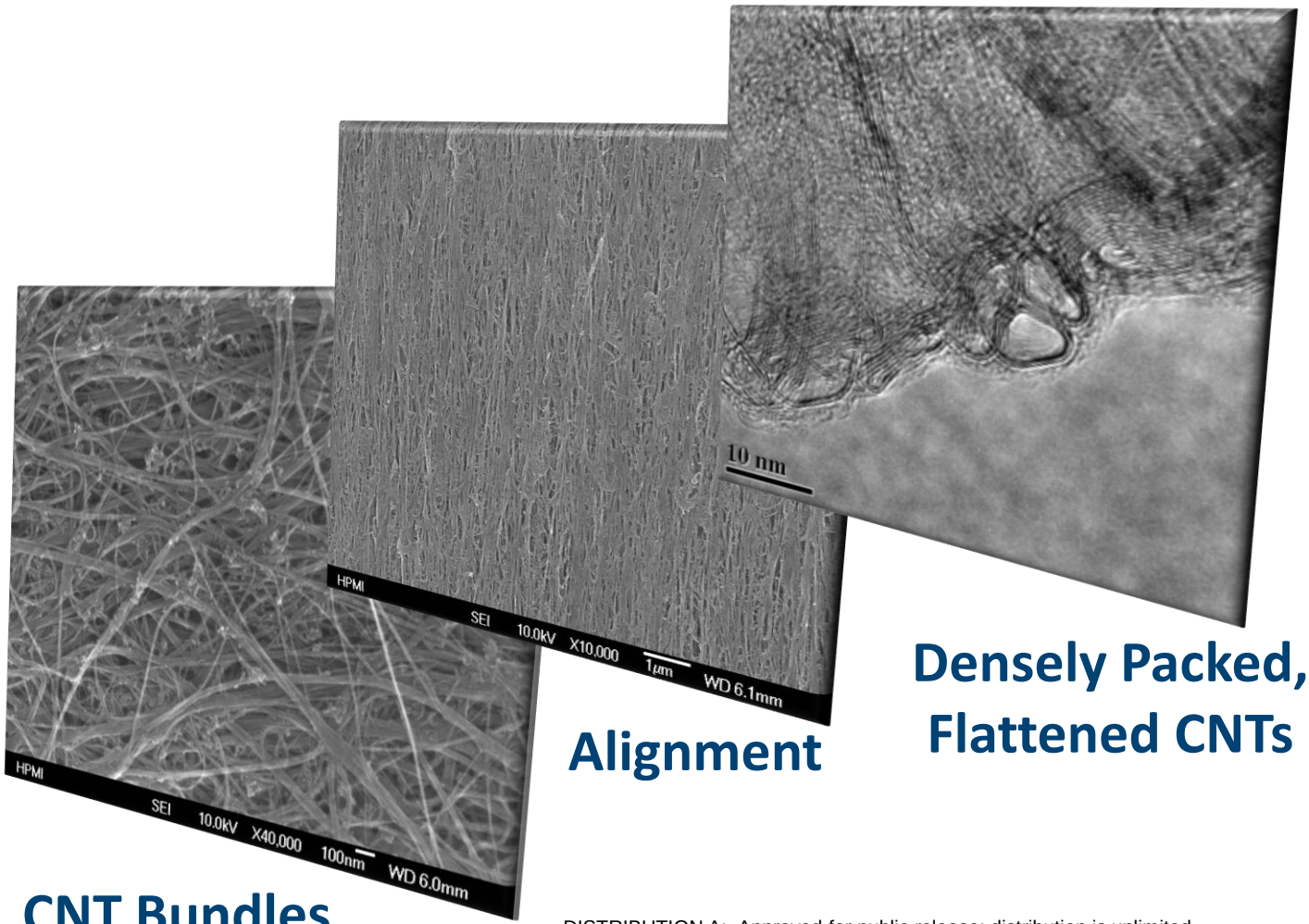
8.7 GPa strength

47% failure strain

2,500 MPA toughness

Translation of Nanoscale Properties to Macroscale Structures

Fundamental Challenge:
Improving CNT-CNT Load Transfer



Densely Packed, Flattened CNTs

Alignment

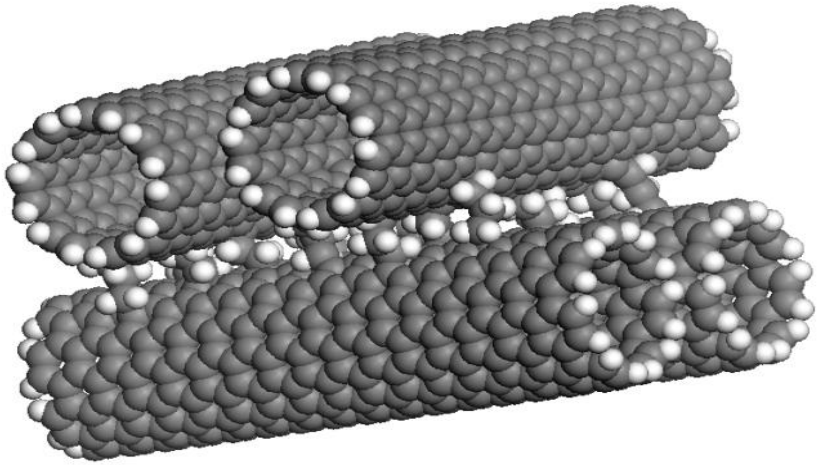
CNT Bundles

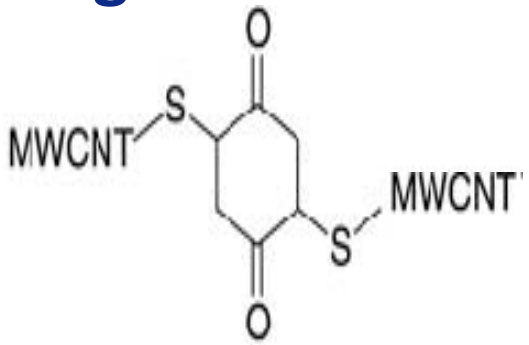
Dr. Ben Wang
Fellow – IIE, SME, SAMPE

Dr. Richard Liang

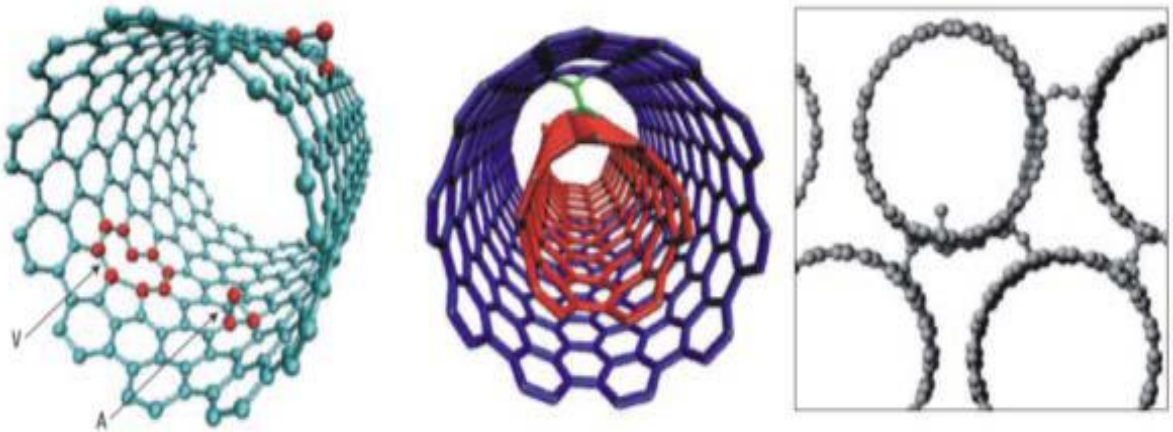
CNT-CNT Reaction Mechanisms

Fundamental Challenge: CNT-CNT Bonding





Crosslinking MWCNTs via Covalent Bonds



Irradiation-induced Crosslinking of CNTs

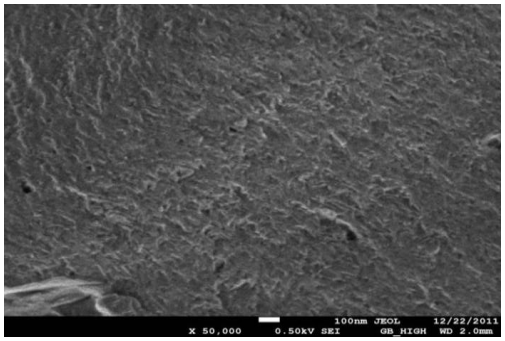
A. V. Krasheninnikov, K. Nordlund, "Ion and Electron Irradiation-Induced Effects in Nanostructured Materials," *J. Appl. Phys. 107, 071301, 2010*

Training Tomorrow's Workforce

(AFOSR DURIP 11) Acquisition of a Thermal Field Emission Scanning Electron Microscope

Nanoparticle Reinforced Resins for Readily Processable, High Temperature, Low Density Composites and Energetic Materials

"The SEM will meet the increasingly stringent requirements of cutting-edge materials technology for fundamental research and the education and research training of students."



SEM of 0.3 wt% graphite/PETI-298, confirming the dispersed graphene

Dr. David Veazie

- 2010 AFRL Summer Faculty Fellow at AFRL/RW
- National Technical Achiever of the Year

SPSU SOUTHERN POLYTECHNIC STATE UNIVERSITY

CAU CLARK ATLANTA UNIVERSITY

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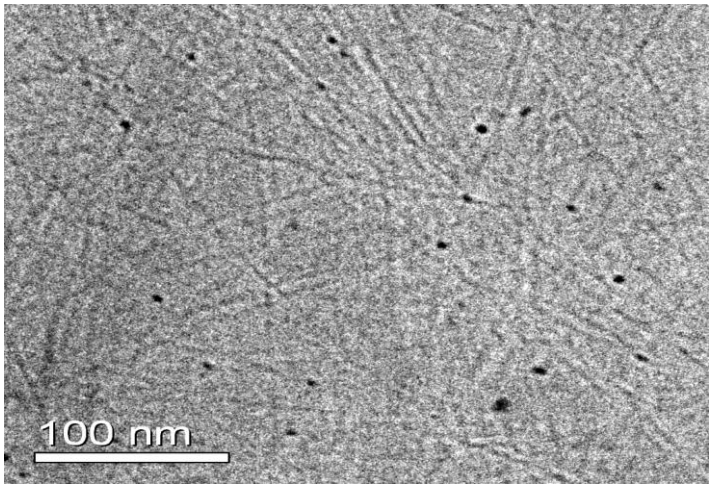
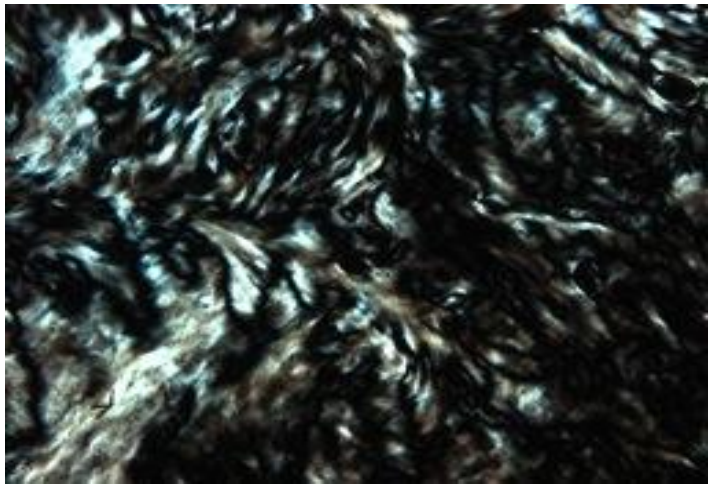
Multifunctionality: CNT Fibers

Liquid Phase Processing of CNTs



Cryo-TEM CNT/ chlorosulfonic acid dispersion



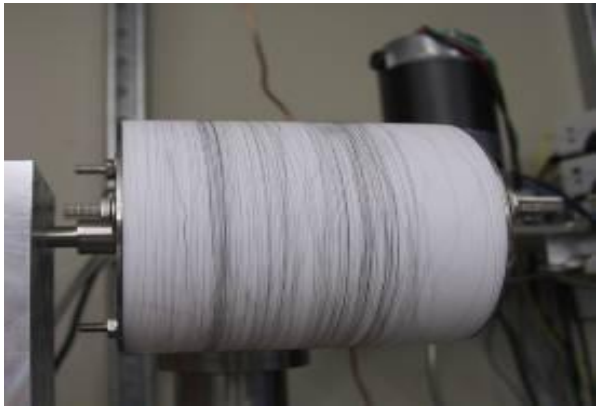
Polarized light micrograph of 10 μm CNT/chlorosulfonic acid dispersion

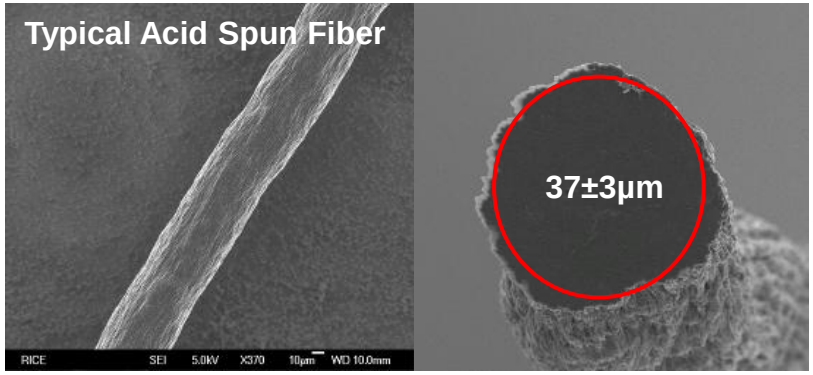
Dr. Matteo Pasquali

RICE

Technology Transfer

Research in collaboration with Teijin Aramids





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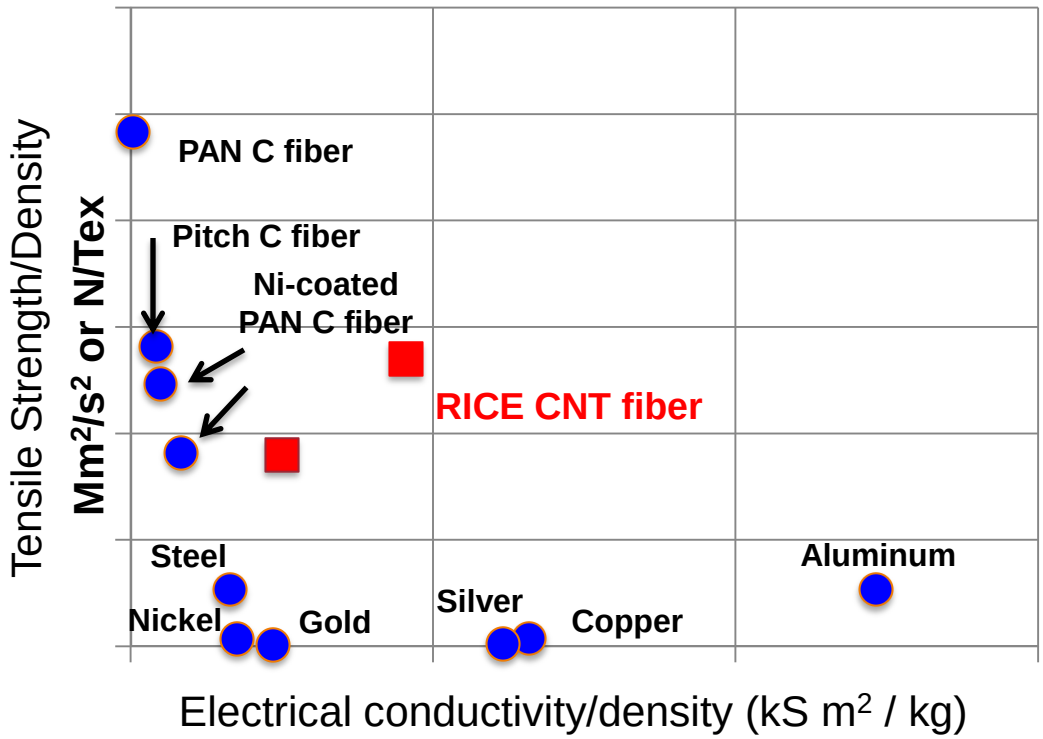
Multifunctionality
Load-bearing + Electrical Conductivity



LED wired and held by "invisible" CNT fibers

- **Best electrical conductivity reported for neat CNT fibers**
- **Order of magnitude increase in electrical & thermal conductivity and strength**

Research in collaboration of Teijin Aramids

Enabling Multifunctionality: Graphene Nanocomposites

Non-covalent functionalization of graphene in solution

GRAPHITE

STATUS QUO: OXIDATION

OUR METHOD: NON-COVALENT STABILIZATION[1]

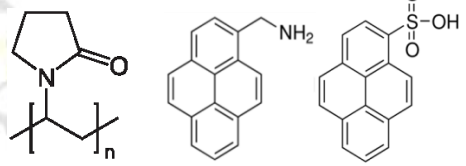
GRAPHENE OXIDE

PRISTINE GRAPHENE

Disadvantage: Insulating, oxidative debris

Advantages: Retains conductivity, stabilizer can be tailored to application

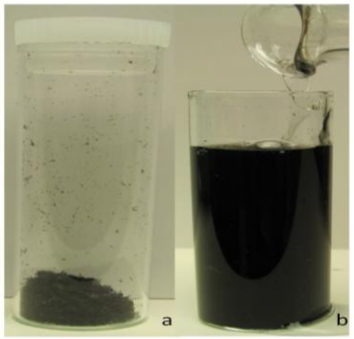
Stabilizers:



PVP π-π stackers

Dr. Micah Green
• 2010 AFOSR Young Investigator Award

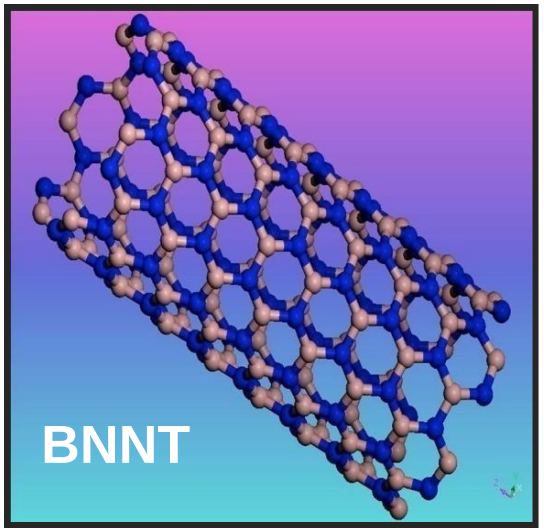
Dispersions are stable against pH changes, heat, lyophilization



Physisorption of PVP on graphene surface guarantees excellent interfacial load transfer[1]

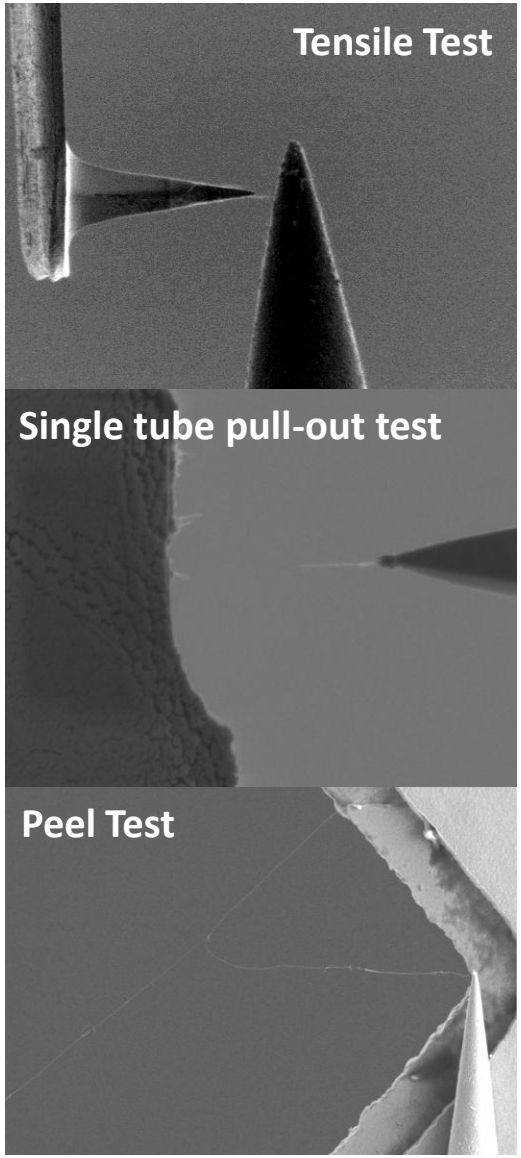
[1]Wajid *et al*, *Carbon*, 2012

BNNT Multifunctionality

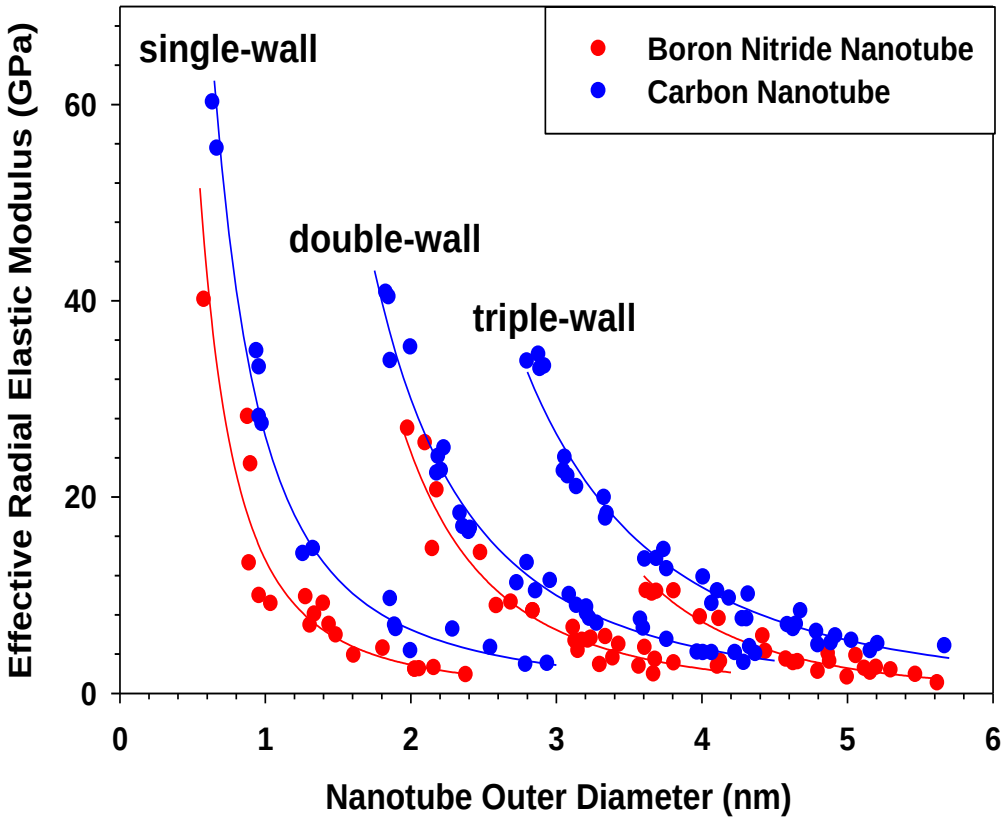


	Carbon nanotubes	Boron nitride nanotubes
Mechanical Properties	1.33 TPa	1.18 TPa
Electrical Properties	Metallic or semiconducting	Semiconducting (~ 5.5 eV band gap)
Polarity	No net dipole	Permanent dipole Piezoelectric ($0.25\text{-}0.4\ C/m^2$)
Neutron Scattering cross-section	C = 0.0035	B = 767 (B^{10} ~3800) N = 1.9
Thermal Oxidative Stability	Stable to 300 – 400 C in air	Stable to 800 C in air

Single Tube Nanomechanics



1st report of radial deformability of BNNT



Dr. Changhong Ke
2010 AFOSR Young Investigator Award

BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK

BNNTs have 40-60% lower effective radial elastic modulus than comparable CNTs

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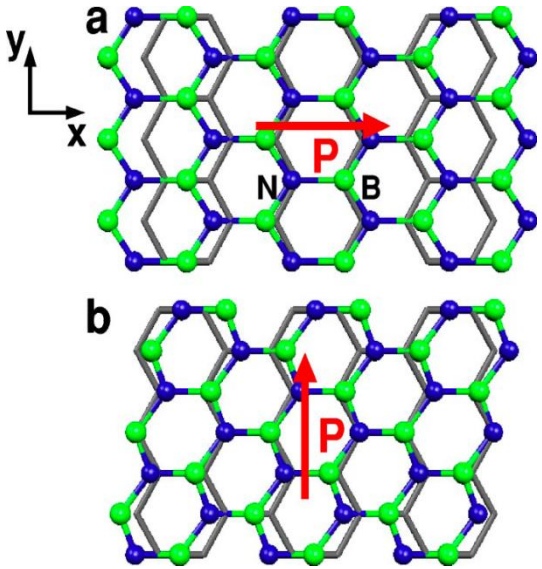
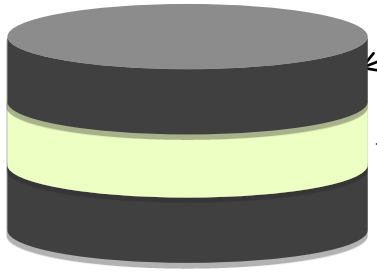
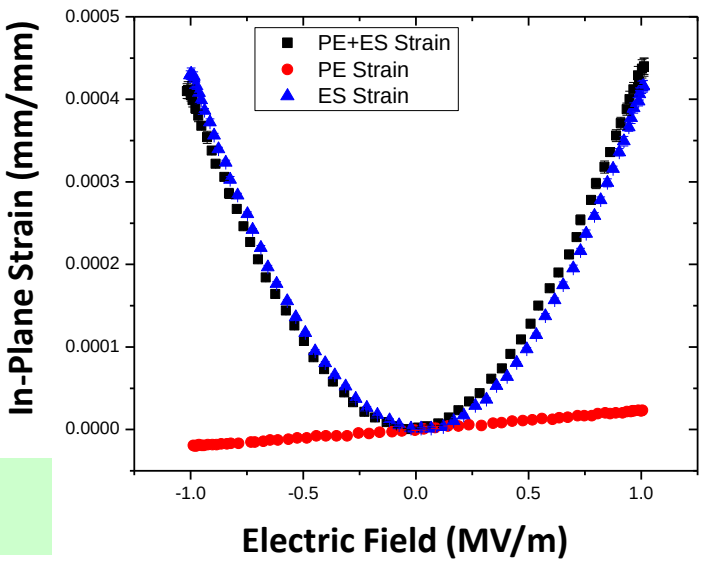
Multifunctionality
Load-bearing + Actuation

1st experimental observation of electrostrictive strain in BNNT

Theoretical Prediction of Net Polarization







Field induced strain (e_{33})

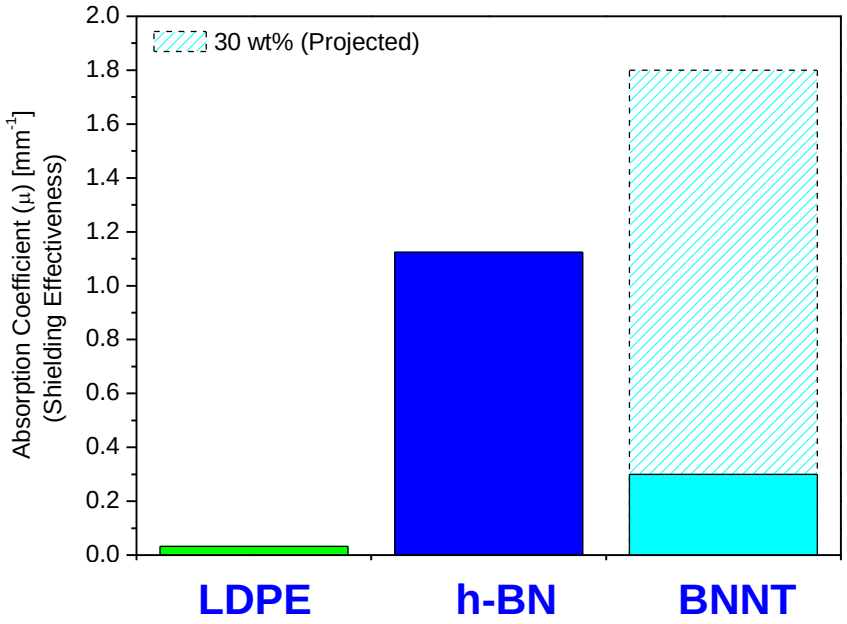
$$e_{33} = d_{33} \cdot E + M_{33} \cdot E^2 + \ldots$$

Dr. Cheol Park

Prof. Alex Zettl
Fellow - APS

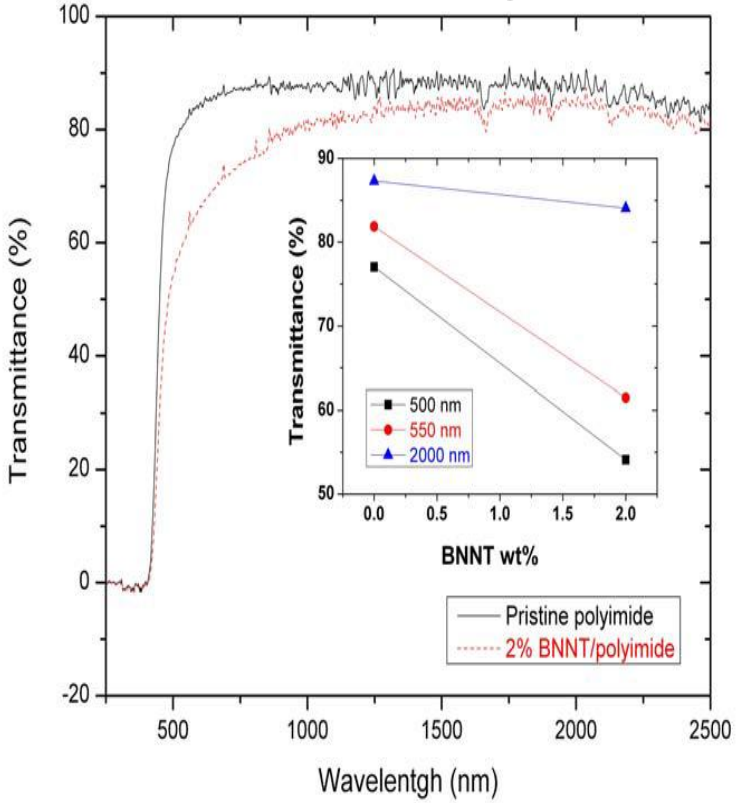
Multifunctionality
Load-bearing + Radiation Shielding

Neutron Shielding



$$\ln(\frac{I_s}{I_0}) = -\mu x, \Rightarrow \mu = \ln(\frac{I_0}{I_s}) \cdot \frac{1}{x}$$

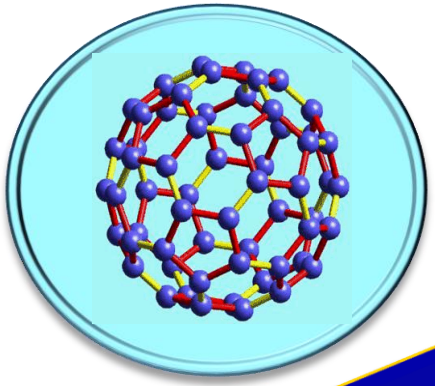
UV Shielding



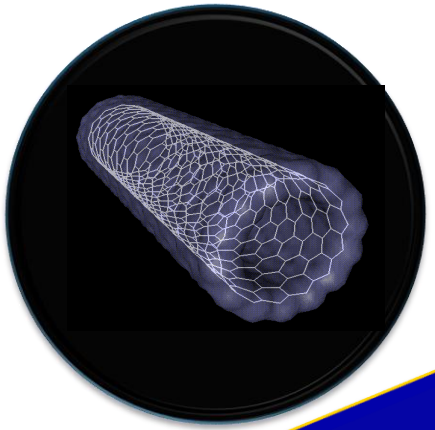
Shielding Effectiveness of BNNT exceeds h-BN on weight basis

Nanostructured Carbon

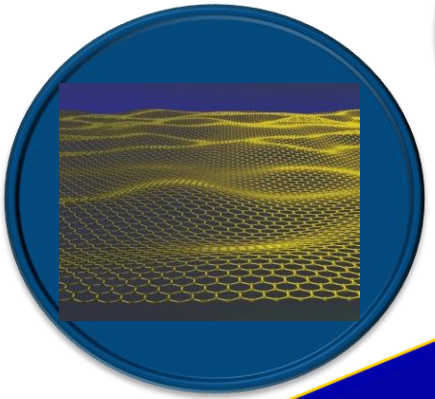
0D
Fullerene



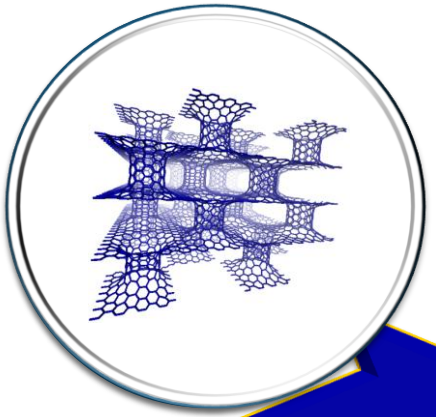
1D
Carbon
Nanotubes



2D
Graphene



3D



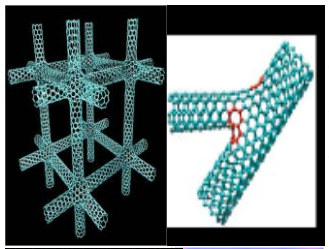
1985

1991

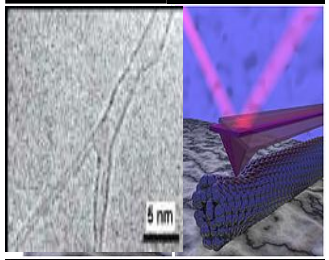
2004

MURI 11 Topic: Nanofabrication of 3D Nanotube Architectures

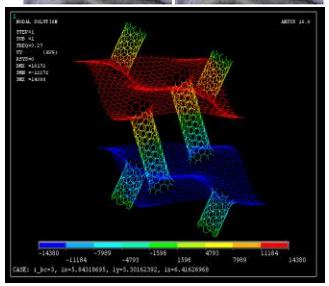
Objective: Controlled assembly and <u>atomic-scale bonding</u> of nanoscale elements (e.g. carbon nanotubes and graphene), leading to network structures with exceptional 3D thermo-electro-mechanical properties



Multi-Path Synthesis and Assembly
- doping-induced branching
- metal nanoparticle-induced branching
- atomic nanotube welders

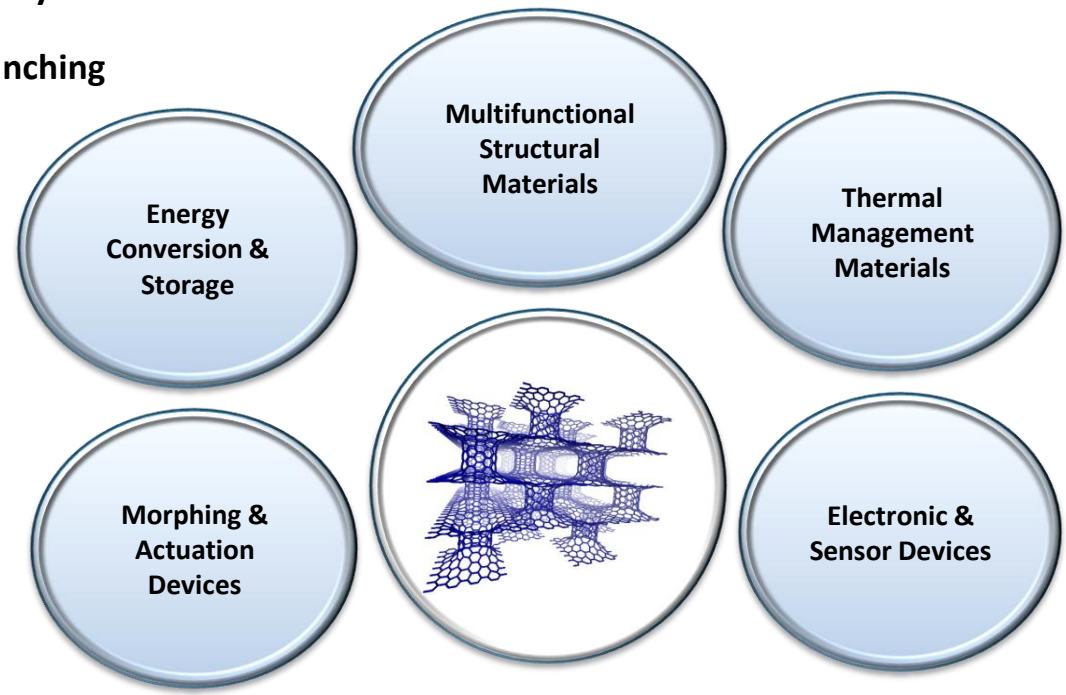


Multiscale Characterization
- atomic scale structure
- node integrity
- mechanical properties
- electron & phonon transport



Multiscale-Multiphysics Design
- density function theory
- molecular dynamics (MD)
- mesoscale/continuum models
- finite element

Materials Enabling Future Aerospace Needs



Synthesis and Characterization of 3D Carbon Nanotube Solid Networks, Rice U. MURI Team

Pulickel M. Ajayan, PI
Synthesis, characterization, mechanical, electrochemical, thermal properties

James Tour
Synthesis, chemistry, devices, electrical properties

Matteo Pasquali
Solvent processing, rheology, fibers, mechanical properties

Boris Yakobson
Ab-initio modeling, simul
structure-property correla
thermo-mechanical properties

Ray Baughman
Synthesis, fiber spinning, mechanical, thermo-mechanical, electro-mechanical properties

Mauricio Terrones
Synthesis, chemical processing, atomic scale characterization, structure modeling

Jonghwan Suhr
Synthesis, modeling, thermo-mechanical behavior, viscoelastic properties, composites

Multidisciplinary, Collaborative Team

RICE · The University of Texas at Dallas · University of Delaware · PennState

AFRL

Nanofabrication of 3D Nanotube Architectures
Case Western Reserve U., MURI Team

Tim Fisher
(Purdue)
"thermal transport & management, nanotechnology"

Zhonglin Wang
(GaTech)
"nanoscale structure & device characterization & novel hybrids"

Zhenhai Xia
(NTU)
"mechanical/electrical multi-scale simulation"

CASE WESTERN RESERVE UNIVERSITY
PURDUE UNIVERSITY
Georgia Institute of Technology
UNT UNIVERSITY OF NORTH TEXAS
KENT STATE UNIVERSITY

THE MURI TEAM

Liming Dai
(CWRU)
"C-nanomaterials syntheses & devices"

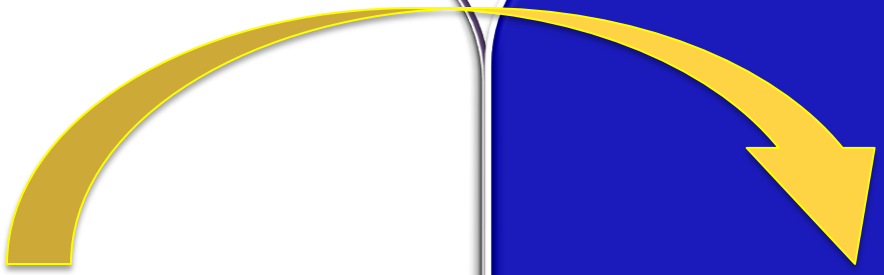
Quan Li
(KSU)
"liquid crystal materials, chemistry, self-assembly"

Vikas Prakash
(CWRU)
"multi-scale structure-property characterization; thermal management"

Xiulin Ruan
(Purdue)
"thermal modeling of *e-p* & *p-p* coupling"

Chung Chiun Liu
(CWRU)
"electrochemistry, sensors & energy devices"

Hybrid Materials Design

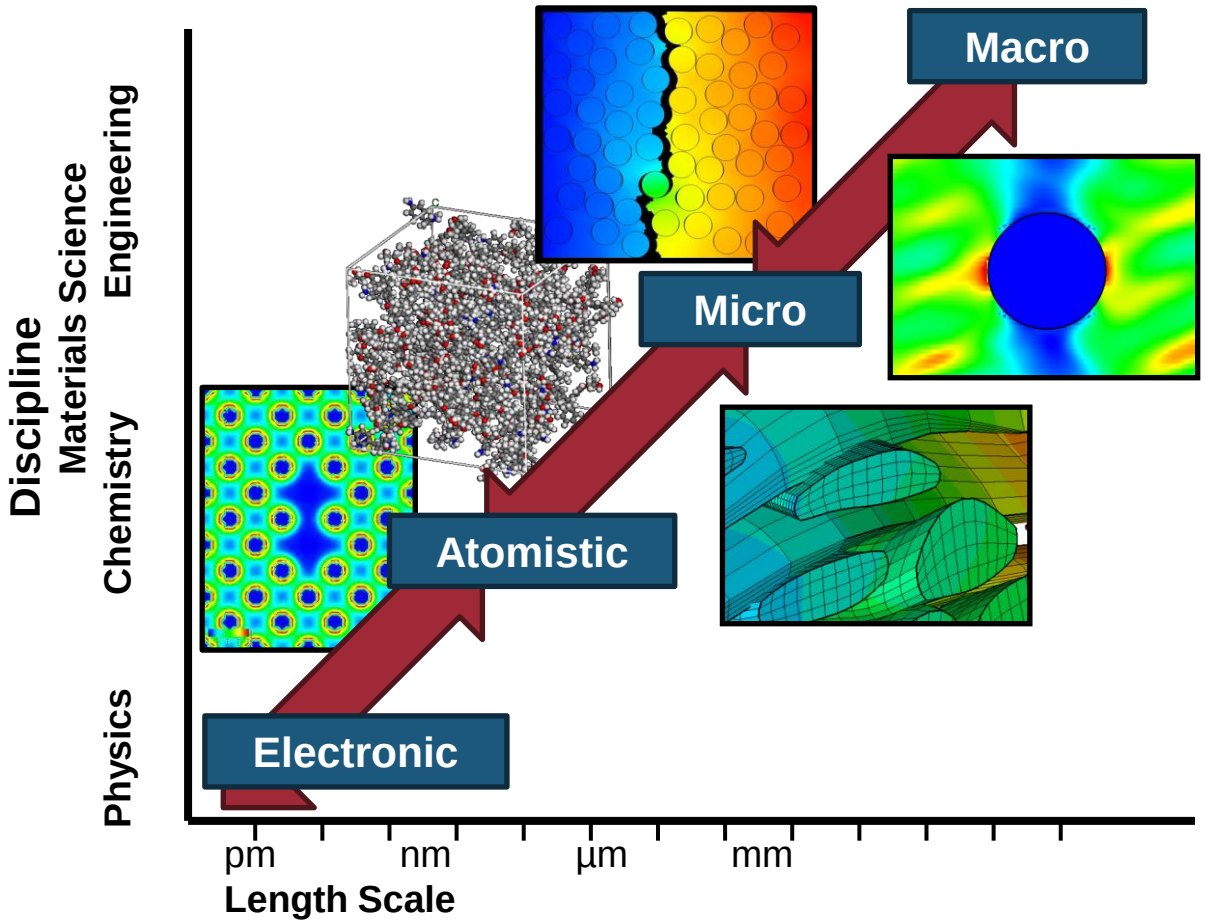


Design the structure based on limitations of the material

Design the material based on structural requirements

Hybrid Materials Design

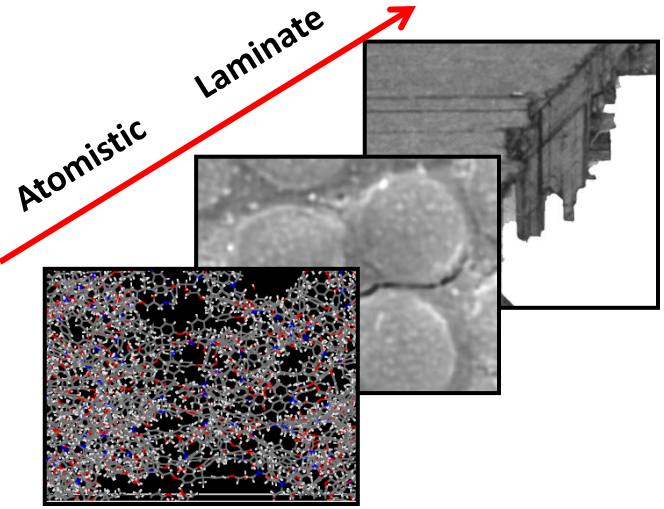
Materials Modeling Hierarchy

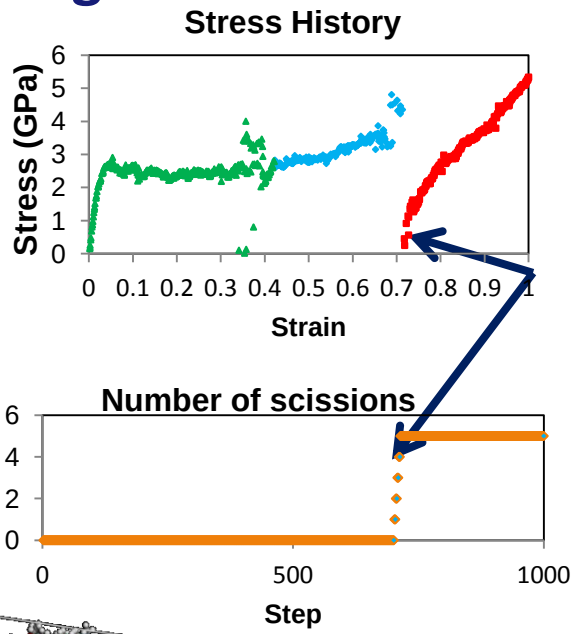


*Slide created by Dr. Tim Brietzman, ARFL/RXBC

Hybrid Materials Design

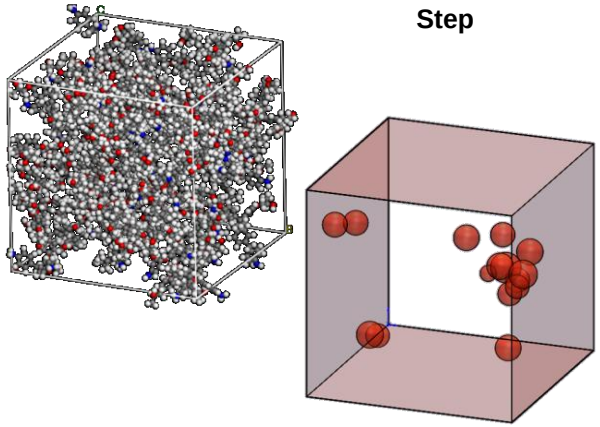
Connecting Atomistic & Microscale Behaviors -- Essential for Materials Design





Polymer network breakdown

Molecular representation of epoxy resin and mapping of nanoscale voids due to bond scission



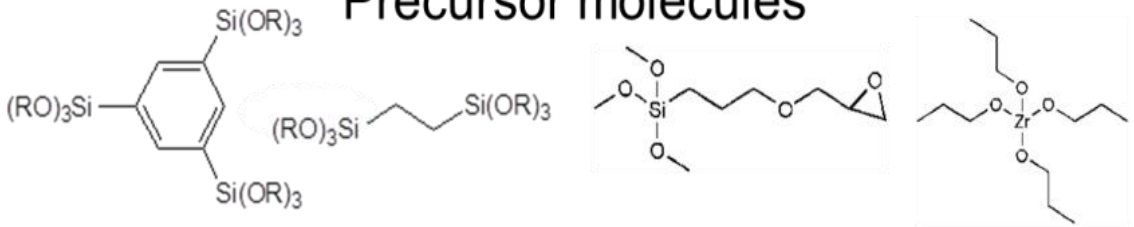
Dr. Tim Breitzman
AFRL/RXBC

Dr. Rajiv Berry
AFRL/RXBN

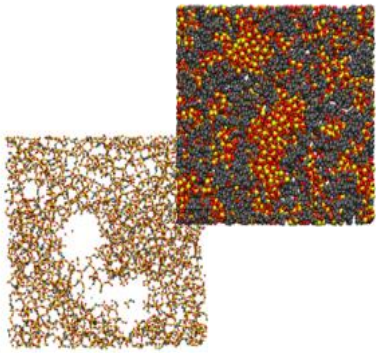
Dr. Jim Moller
MIAMI UNIVERSITY

ICMSE Hybrid Materials Design

Precursor molecules



3D hybrid models

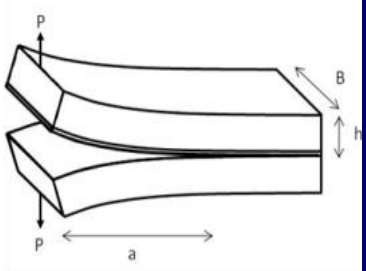


Synthesis

Rapid Hybrid Materials Development

Molecular Modeling

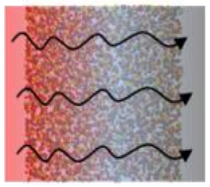
Experiment



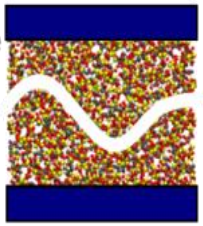
mechanics

property simulation:

Elastic

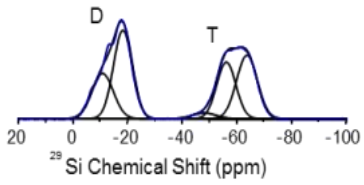


Fracture

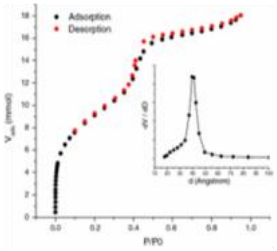


Thermal

^{29}Si NMR



porosimetry



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STANFORD
MATERIALS SCIENCE AND ENGINEERING

AFRL

2011 Basic Research Initiative

AFOSR/NSF Joint Research Solicitation

ODISSEI: Origami Design for Integration of Self-assembling Systems for Engineering Innovation

Advance understanding of folding and unfolding of materials structures across scales for design of engineered systems

- **Packaging/Deploying Control Surfaces**
  - Satellites
  - Solar sails
  - Precision air drop
  - Tube launched systems
- **Mechanisms**
  - Compliant mechanisms
  - Actuators
- **Materials**
  - Hierarchial materials design
  - Atomistic assembly
  - Active/tunable materials

Research Community Leadership

AFOSR Low Density Materials

AFRL DIRECTORATES

RX, RV, RW
LRIRs, STTRs,
MURIs,
Workshops,
Reviews, Visits

INTERNATIONAL

US-India Tunable Materials Forum

US-AFRICA Initiative

DOD COMMUNITY

Reliance 21 Board Materials and Processing COI

OTHER AGENCIES

Lightweight Structures

Nanostructured Materials

Origami Engineering

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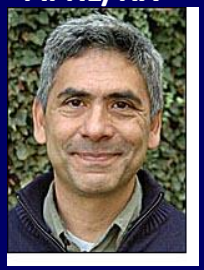

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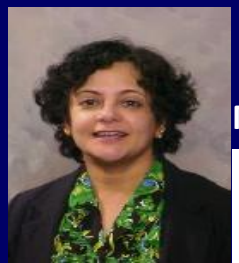

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